THE CATHODE-RAY FLUORESCENCE

OF

SODIUM VAPOR.

DISSERTATION

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BY

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THE CATHODE-RAY FLUORESCENCE

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SODIUM VAPOR.

The vapor of metallic sodium, because of its remarkable optical and spectroscopic properties, has been the subject of an extended investigation by Professor R. W. Wood which has furnished much information regarding the mechanics of molecular radiation. When subjecting the vapor to an electric discharge, a new spectrum was accidentally discovered entirely different from anything ever seen in the flame, arc or spark, and appearing to have no relation to the absorption, fluorescent or magnetic rotation spectra. Cathode rays were found to excite, in addition to the green fluorescence stimulated by white light, a curious banded spectrum in the red, orange and yellow region. A report of preliminary work on this spectrum was published by Professor Wood in the Philosophical Magazine (S. 6, Vol. 15, No. 89, 1908) and in the Proceedings of the American Academy of Arts and Sciences (November 1908). The present paper is a further study of this spectrum.

Apparatus.

The apparatus was essentially that described by Wood in the papers referred to. The vacuum tube was made of steel, 36 cm. long and 3.3 cm. in diameter, and was connected by a side tube to a mercury pump. As shown in Figure 1, the steel tube itself formed the negative electrode; the positive electrode was a nickel wire carried in a glass cap cemented with sealing wax to one end of the steel tube. The electric discharge passed from the end of the nickel rod, inside steel tube. The opposite end of the steel tube was closed by a glass or a quartz window.

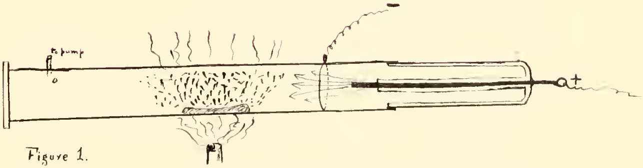

Figure 1.

The current was obtained from an induction coil capable of sparking ten inches in air. Two spectroscopes were used. To obtain general characteristics of the spectrum, a quartz spectrograph, made by Fuess, was employed; for accurate wave-length determinations a Rowland concave grating of six feet radius of curvature, 15,000 lines

to the inch, was used. The plates used for the red and yellow were Cramer's New Spectrum plates; for the green and blue, Wrattan and Wainwright's Green Sensitive Plates.

The steel tube was heated by means of a single bunsen burner, the use of a hotter flame being prohibited by two facts: the higher the temperature, the longer was the column of vapor, and hence the greater the absorption; and, with too intense heating it was impossible to keep the ends of the tube cool enough to prevent a fog from forming on the window. Cooling was effected by pouring cold water on cotton batting wrapped around the ends of the tube.

To obtain the spectrum, a piece of clean sodium (about 8 cu. cm.) was placed in the middle of the tube, and the pressure reduced to a few millimeters of mercury. The flame was then applied and the pumping continued until most of the occluded hydrogen was removed. When the pressure was two mm. or higher, if the current was turned on from the coil the ordinary secondary spectrum of hydrogen was obtained whether the tube was heated or cool. If the tube was kept hot at a little less than 2 mm. pressure the hydrogen glow began to give way to the sodium discharge. A bright yellow ring of light, touching the inner wall of the tube, appeared over the molten

sodium, and as the pressure decreased, this light became more and more intense, contracting toward the center of the tube as the cathode dark space widened. The whole of the discharge took place through the sodium vapor. The sodium light was most intense when it was scarcely possible to draw off any more gas through the pump. Then the discharge viewed from the window at the end of the tube, appeared as an orange-yellow disk of almost insupportable brilliancy, usually completely detached from the wall of the tube. This luminous disk evidently was the negative glow seen end on, it being a solid cylinder along the axis of the tube, over the sodium. An image of the luminous disk was thrown on the slit of the spectroscope by means of a lens.

On looking into the tube through the window in an oblique direction, the negative glow has a curious appearance. Behind the brilliant disk, near the window, the column of vapor was almost non-luminous, and at the tip of the positive electrode there was a green spot of light. Viewed from the other end of the tube this spot of light was seen to be orange-yellow, its apparent green color when seen through the window being evidently due to absorption. The reason why

the central part of the column of vapor was non-luminous is not at once evident; but it may be that the current passed almost entirely through the vapor at the two ends of the column, where the vapor was diluted with hydrogen, the most dense vapor carrying practically none of the current. This would presuppose that the sodium vapor conducts better if it is mixed with hydrogen.

Characteristics of the Spectrum.

Plate 4 shows the spectrum obtained by the quartz spectrograph. Close inspection shows that it may be divided into two parts: bands, and isolated lines. Plates 1, 5 and 6 show the spectrum given by the grating; the details of the spectrum will now be discussed.

(1). Red and Yellow Bands.

Plate 1 shows that the red and yellow portion of the cathode-ray fluorescent spectrum consists of a number of bands. Sixteen of these are distinguishable on the negative of which plate 1 is a positive, enlarged three-fold. The negative was exposed for three hours; with a longer exposure more bands could probably be obtained, since faint lines run out as far as 6864$\mu\mu$.

The spacing of the bands is approximately even with respect to wave length, (see Table 1), the mean difference between the

centers of intensity of the adjacent bands being 54.7 μμ. It is interesting to note that this spacing is of the order of magnitude of the spacing of the resonance fluorescent lines* excited in this region by the lithium lines 6104 and 6708 μμ.

These red and yellow bands are much less symmetrical than the green fluorescent bands excited by white light; the lines in these cathode-ray bands are irregularly distributed, having no suggestion of a head or tail.

The best conditions for obtaining these red and yellow bands were, a fresh supply of sodium in the tube; a high vacuum (about 1/10 mm.); high potential discharge; high temperature. The high potential was especially important. When the potential was rather low nothing except the D lines appeared; but when the e.m.f. of the coil was gradually increased a critical value seemed suddenly to be reached at which the banded spectrum flashed out at all almost full brilliancy. This e.m.f. was such as to give a spark of about seven inches in air. Plate 4 shows the spectrum obtained with three different temperatures: I, with a low flame; II, medium flame; III, high flame.

The wave-lengths of the lines in these bands are given in Table II at the end of the paper, the standard comparison lines

* R. W. Wood & F. E. Hackett. Astrophys. Journ. Dec. 1909.

(shown on plate I) being those of the barium arc. A comparison of these red and yellow bands with the absorption spectrum shows that there is no relation between the two spectra. Plate 2 (a three-fold enlargement) shows the spectra side by side, the barium arc lines being superposed upon the absorption spectrum.

A curious relation exists between the cathode-ray spectrum and the fluorescent spectrum excited by white light at pressures of about one centimeter. Plate 7 shows that the dark bands of the cathode-ray spectrum coincide with the bright bands of the fluorescent spectrum. An entirely different fluorescence, in no way related to the cathode-ray spectrum, is obtained from sodium vapor at pressures of two or three millimeters.

(2). Green Bands.

The portion of the cathode-ray spectrum lying between 5300 and 4000 μμ is shown in plate 6. A series of fourteen bands lies in the green, between 5200 and 4750 μμ. It is found that these coincide with the green fluorescent bands excited by white light. They appear under the same conditions as the red and yellow bands just described.

The coincidence of the green cathode-ray bands with the green white-light bands, together with the lack of agreement between the two

spectra in the red, suggest that the appearance of the green bands in the cathode-ray spectrum may be a secondary effect. It may be that the cathode rays excite the lines of the subordinate series (as shown in plate 6) which lines in turn excite by resonance the green fluorescence. The lines of the subordinate series between 5200 and 4000 are so numerous that the resonance spectrum due to them would appear almost identical with the white light spectrum. The absence of the resonance spectrum in the yellow and red is due to the fact that there are so few strong exciting lines in that region. This hypothesis as to the secondary origin of the green bands is supported by the fact that their intensity is much less than that of the red cathode-ray bands.

(3). Blue and Violet Bands.

These bands are shown in plates 5 and 6; the blue band lying between 4541 and 4498 μμ, the violet band between 4390 and 4340 μμ. A weak continuation of the violet band extends as far down as 4210.

Neither of these bands are resolved; hence they must be totally different from the bands found by Zickendraht* in this vicinity. His bands were in the spectrum of the negative pole of an arc burning in

* Ann. No. 2, 1910.

sodium vapor, at a pressure of 26 mm. He was enabled to resolve his bands with a prism giving about one fourth the dispersion attained with a grating in plate 6.

The blue band is seen from plate 6 to be slightly less than the strongest of the green bands; the violet band, between 4330 and 4345, is more intense than this green band.

Plate 4 shows that these two bands appear under the same conditions as the red and green bands.

(4). Ultra-Violet Band:

There is another band in this spectrum which lies about 3910 $\mu\mu$ and which consists of a number of well defined lines. In the plates taken with the quartz spectrograph, this band is unresolved. In some of these plates it is present with varying intensity; in other plates it is absent. Plate 4, II shows that this band comes out strongest when the temperature was not high enough to give the other bands strongly; i.e. this band is absorbed when the sodium vapor is made dense by heating beyond a certain point. Even under these conditions it did not always appear.

(5) Lines:

Plates 1,5 and 6 show numerous bright lines in the sodium spectrum. Evidently a large number of these lines belong to

the first and second subordinate series.

In the ultra-violet there is a series of lines which coincide generally with the spark lines. These ultra-violet lines are shown by plate 4 to be strongest when the bands are weakest, i.e. at low temperatures.

At a certain stage in the warming of the sodium the spectrum was found to contain the secondary lines of hydrogen. When a pressure of about 1 mm. was reached just when the yellow sodium light began to appear these hydrogen lines came out strongly. Usually they disappeared as soon as a slightly higher vacuum was obtained; but once they were present for a considerable length of time and were recorded on a plate together with the sodium spectrum. This hydrogen spectrum could be obtained with the tube cold as in an ordinary hydrogen vacuum tube. Plate 3 shows these hydrogen lines (each marked with an X) superposed on the cathode-ray spectrum.

SUMMARY.

A new spectrum is obtained from the negative glow of a vacuum tube containing sodium vapor. This spectrum shows the D lines, the first and second subordinate series, the green fluorescent bands excited by white light, a series of symmetrical bands in the red and

yellow, and three bands in the blue and violet, and the spark lines. The red and yellow bands and the violet bands have been found in the [illegible] spectrum of [illegible] vapor.

The cathode-ray fluorescent spectrum was first observed by Professor R. W. Wood. The author wishes to record his thanks to Professor Wood for suggesting this investigation, and for directing it; and to express to Professor [illegible] his sincere appreciation of the interest and encouragement shown throughout the work.

Table I.

Red and Yellow Bands.

Band	Wave-length	Difference.
I	6564	44 $\mu\mu$
II	6520	65
III	6455	67
IV	6388	60
V	6328	52
VI	6276	53
VII	6218	54
VIII	6164	52
IX	6112	59
X	6053	53
XI	6000	54
XII	5946	52
XIII	5894	51
XIV	5843	51
XV	5792	48
XVI	5744	
		Mean 54.7 $\mu\mu$

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
1	6864.1	1	6809.0
	60.4		06.7
	54.5		05.0
	48.6		02.3
	44.9		6799.3
	41.9		97.5
	39.2		93.7
	36.1		93.0
	33.7		90.3
	31.6		87.2
	28.5		86.7
	25.6		33.2
	22.2		81.3
	21.0		80.2
	19.1		78.8
	17.4		75.6
	16.1		72.9
	14.6		69.3
	11.9		66.6

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
1	6763.2	1	6720.5
	60.7	1	18.2
	58.1	1+	15.9
	56.9	1+	14.4
	55.5	1-	11.6
	54.2	1	09.7
	52.7	1-	08.2
	50.8	1	06.6
	48.5	1	04.9
	45.5	1	03.1
	43.2	1+	00.5
	41.4	1+	6699.8
	40.2	1+	97.2
	38.5	1+	95.4
	36.5	1	93.3
	34.7	1	91.6
	33.6	1	90.3
	29.0	1	88.9
	26.8	1	86.9
	24.9	1	84.6
	22.7	1+	82.6

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
1+	6680.5	1	6645.4
1	78.5		43.1
	77.5		41.8
	75.2		37.3
	72.7		36.0
	71.0		29.0
	69.6		27.3
	68.2		23.6
	66.6		23.1
	65.0		21.4
	63.1		19.7
	59.1		16.0
	58.8		12.9
	57.1		12.4
	55.8		11.5
	54.2		10.3
	52.0		08.5
	50.8		06.4
	49.2		00.4
	47.3		6598.5

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length.
1	6594.6	1	6556.8
1	93.1	2	53.1
1	91.0	1	50.9
1	89.4	1+	49.6
1	87.7	1	48.2
1	86.0	1	46.1
1+	83.8	1	44.3
1	82.3	2	42.7
1	81.0	1	41.2
1	80.2	1	40.1
1+	77.6	1+	3[illegible].9
1	76.5	1	37.9
1	75.7	1	36.4
1	74.2	1	32.9
1	73.0	1+	30.6
1	71.7	1	29.3
1	70.2	1	27.2
1	61.3	1	25.8
1	58.5	2	21.1

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
2	6515.2	2	6486.3
1	14.5	1	[illegible]
1	13.2	1	80.2
2	11.8	1	79.1
1+	10.8	1	76.3
1	07.1	1	75.2
2	05.7	1	72.3
1	04.1	1	68.4
1+	03.1	1	66.4
1+	01.4	1	64.4
1+	6499..5	1	61.4
1+	98.8	1	60.6
1	96.4	1	58.2
2	94.8	1	55.9
1	92.5	1	54.2
1+	90.9	1	51.7
1	89.6	1	49.6
1	87.2	1+	47.3
1	85.4	1	44.4

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
1	6442.1	1	6401.0
1	39.6	2+	6399.6
1	36.8	1	97.7
1	34.5	2	96.3
1	32.9	1	94.7
1	30.4	3	92.8
1	28.2	2+	90.6
1	26.0	1	88.6
1	24.0	2+	87.2
1	21.4	1	85.9
1	19.0	1	83.7
1	16.4	1+	82.2
1+	13.9	2	78.9
2+	11.3	2+	77.7
2	09.9	2+	75.5
1	07.0	2+	71.2
1+	05.8	3	70.1
1+	05.0	1	69.1
1+	03.5	1	61.6
2	02.5	1	62.7

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length.
1	6360.7	1	6329.6
1	56.8	1+	27.6
1	54.9	2	25.5
1	53.4	1	23.0
1	51.8	1	21.7
1	50.6	1	20.5
1	49.2	1	19.1
1	47.6	1	17.2
1	46.4	2	15.7
1	45.3	1	14.2
1	44.2	1+	12.9
1+	42.6	1	11.0
1	40.7	1	09.1
1	3 .1	1	06.9
1	37.5	1	04.3
1	36.2	1	02.0
1+	34.5	1	00.1
1	32.6	1+	6298.4
2+	31.0	1	96.2

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
1	6292.7	1	6258.4
1+	90.6	1	56.3
1+	87.9	1	52.1
1	86.2	1	49.8
1	84.5	1	47.4
1+	84.3	1	44.9
1	81.4	1	42.1
1	80.0	1	40.5
1	78.5	2	38.0
1	77.0	1+	36.1
1	75.6	1+	34.9
2	74.5	1	32.3
2+	72.2	1	31.6
1+	69.8	2	30.2
1	69.0	1	29.3
1	66.5	1	27.6
1+	65.1	3+	25.7
1+	64.3	2	24.0
1	61.4	1+	22.0

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length.
3	6220.2	1	6183.3
2+	18.2	1	82.1
1+	16.3	1	80.7
2	14.4	1	78.3
1	12.3	1	76.8
1	11.0	1	75.4
2	09.7	1	74.4
1+	07.9	1+	73.2
1	06.3	1	71.9
1	04.5	2	69.9
1	02.3	2	67.2
1	00.3	2	65.6
1	6199.1	2	64.5
1+	96.7	2	64.3
1	94.5	1+	57.8
1	92.9	1	56.1
1	91.5	1	50.9
1	89.6	1	50.0
1	88.2	1	44.9

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length.
1	6142.9	2+	6105.[illegible]
1	40.6	2+	03.4
1	38.9	2	00.8
1	36.4	1	6099.4
1	34.0	1	97.1
1	31.4	1	95.7
1	30.6	1	94.3
1+	28.4	1	91.8
1+	23.1	1	89.1
2	21.2	1	87.1
1+	19.6	1	83.4
1+	17.8	1	79.6
1	16.5	1	77.6
1	14.8	1	74.4
1	13.3	1+	72.0
1	11.6	1	70.9
1	10.1	1	69.6
1+	08.8	2	6[illegible].2
1	07.3	1+	66.0

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
1	6064.5	1	6033.5
4	63.2	1	32.4
4	62.3	1	30.8
1+	61.0	1	29.5
2	58.4	1	28.4
2	56.5	1	27.2
4	54.8	1	26.7
3	53.5	1+	18.3
3	52.0	2+	15.9
3	51.0	2	12.9
3	49.7	1	11.3
3	48.4	2+	09.7
3	47.1	3	07.8
3	45.8	3	05.7
3	44.4	1	04.1
2	42.3	2	03.0
2	40.0	1+	01.5
3	38.0	5	5999.6
1+	35.6	4	98.5

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
1+	5997.5	2	5958.5
6	96.3	3	57.2
6	95.0	2	55.7
3	93.9	3	54.1
3	91.5	3	53.1
3	89.3	2	52.4
3	86.2	5	50.4
1	83.8	6	48.8
1	82.7	3	47.4
1	81.3	4	45.4
2	79.9	6	44.4
1	77.8	7	42.7
1	76.4	7	41.6
1	74.9	4	39.7
1	73.3	4	38.7
1	72.1	4	36.9
1	70.0	4	35.3
3	63.8	4	32.4
2	62.0	4	30.7
4	60.6	3	27.9

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
3	5926.8	3+	5839.1
3	25.5	3	37.4
2	24.9	3	35.8
4+	23.1	2+	29.7
5	20.1	2+	28.3
5	16.8	2	17.4
6	13.3	1+	15.2
7	10.4	1+	07.9
9	08.0	1+	05.8
20	5896.2	1+	04.2
20	5890.2	1+	01.0
7	78.[illegible]	2+	5798.4
6	72.4	1+	96.9
5	66.7	2	95.5
3	55.2	2	93.8
2+	51.7	1	92.4
2+	49.6	1+	91.2
2+	46.8	3	90.2
4	44.2	2+	88.6
3	42.7	2	87.0
3+	41.1	2+	84.6

Table II. Red and Yellow Spectrum.

Intensity	Wave-length	Intensity	Wave-length
1	5783.5	1	5704.5
1	81.4	1	01.3
2	79.3	1	5699.2
1	52.7	1	97.5
1+	50.7	1	95.8
2	48.3	1	93.1
2	46.5	1	92.0
2	43.7	1	88.4
1-	42.2	1	87.3
2	40.6	1	82.8
1+	39.0	1	81.8
1	37.5		
1	35.7		
1	33.3		
1	30.8		
1	29.1		
1	13.9		
1	09.9		
1	09.0		
1	06.5		

Table III: Green Banded Spectrum.

Intensity	Wave-length.	Intensity	Wave-length.
1	5356.1	1	4991.8
1	5240.1	1	86.2
1	5233.4	3	72.5
3	5187.5	4	68.6
3	80.2	9	63.4
3	73.7	1	59.7
3	46.4	1	45.4
3	40.3	8	39.3
3	39.0	10	33.5
5	32.9	1	28.9
3	30.4	1	24.5
4	26.9	1	22.5
2	3.8	1	21.1
2	19.6	5	12.6
5	5097.4	4	04.2
6	95.0	3	4896.3
4	92.2	9	95.2
5	89.6	2	84.5
5	87.5	2	78.3
3	85.5	2	75.7
3	80.4	3	73.0
2	71.9	5	68.7
3	68.5	10	66.1
3	63.2	4	49.1
3	59.8	7	38.4
3	55.2	1	22.8
7	49.1	4	19.7
7	44.9	5	14.2
7	39.3	5	10.1
2	35.7	1	02.9
2	30.3	4	4796.9
2	26.0	4	93.5
2	21.1	2	83.9
2	17.4	1	77.5
3	13.8	3	67.8
4	10.5	1	63.4
7	07.0	1	57.8
8	01.9	1	42.6

Table III. Green Banded Spectrum.

Intensity	Wave-length.
2	4734.8
2	31.9
2	28.9
2	23.5
2	19.3
2	09.2
1	4685.8
1	82.4
2	79.9
1	31.3
1	28.0
1	17.5

PLATE 1. Sodium vapor cathode-ray fluorescence.
Comparison: Barium arc.

PLATE 2. Sodium vapor cathode-ray fluorescence.
Comparison: Sodium absorption, Barium arc superposed.

PLATE 3. Hydrogen secondary spectrum superposed upon
Sodium vapor cathode-ray fluorescence.
Comparison: Barium arc.

PLATE 4. Sodium vapor cathode-ray fluorescence.

PLATE 5. Sodium vapor cathode-ray fluorescence.
Comparison: Iron arc.

PLATE 6. Sodium vapor cathode-ray fluorescence.
Comparison: Iron arc.

PLATE 1.

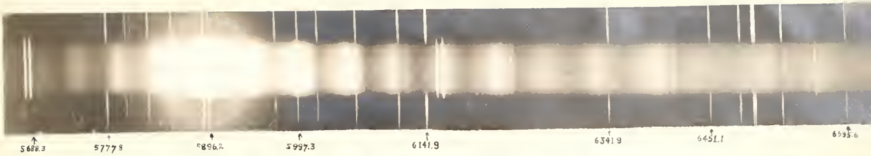

PLATE 2.

PLATE 3.

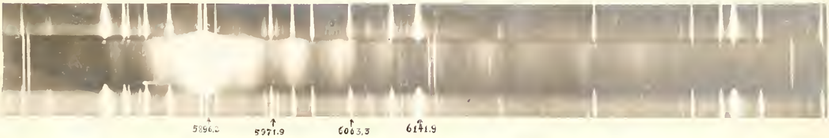

PLATE 4.

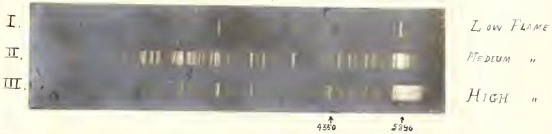

PLATE 5.

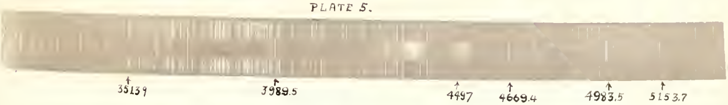

PLATE 6.

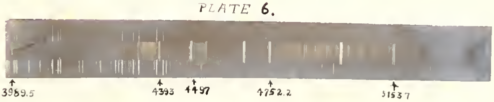

PLATE 7.

BIOGRAPHY.

Rogers Harrison Galt, the son of Commodore Rogers H. Galt, U. S. N. and Mary Meares his wife, was born on July 3, 1889 in San Francisco, California. In 1904 he graduated from the Public High School of Lynchburg, Va. In 1907 he received the degree of Bachelor of Arts at the Johns Hopkins University, where he began graduate work in Physics in October of that year. He held a Virginia Scholarship in 1907-08, and in 1909-10. He was Student Assistant in the Physical Laboratory in 1908-09.

During his graduate work courses have been taken under Professors Ames, Wood, Whitehead, Cohen, Anderson and Jones, and Mr. Jewell.